Project title:	To identify pre-harvest, harvest and post-harvest management practices capable of reducing losses of pumpkins during storage
Project number:	FV439
Project leader:	Debbie Rees, Produce Quality Centre, Natural Resources Institute (NRI), University of Greenwich.
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Location of project:	Natural Resources Institute
Industry Representative:	David Murfitt, Oakley Farms
Date project commenced:	15 September 2014
Expected completion date:	28 February 2017

DISCLAIMER

[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headlines:

- During 2015 the main cause of storage losses observed for pumpkins in Cambridgeshire and Hampshire was *Phoma*. In the final year of this project a spray programme against both *Phoma* will be assessed for efficacy and economic value.
- Spraying against Powdery Mildew increased yield for Mars, and increased pumpkin size for all three varieties tested; Mars, Harvest Moon and Racer.

Background

The UK market for decorative (carving) pumpkins, currently estimated at £14-15M per year, is growing at a rate of 20% annually, and the market for culinary (edible) pumpkins is growing at an even faster rate from a much lower sales base. The levels of loss are estimated to be 15-20% of initially harvested crop, equating to an annual loss of £2-3M. This project seeks to identify and test practices to reduce these losses.

There is currently very little information on the relative importance of different causes of loss and the impact of pre-harvest, harvest and post-harvest management practices on these losses. In this project we are working closely with UK growers to understand the current situation through structured observations on-farm, field and storage trials. Recommendations provided to and practices used by growers in the USA have been reviewed, both through the literature and by direct consultation. By studying a range of decorative and culinary varieties, the characteristics associated with good storage potential will be identified.

Summary

The overall project aim is to identify pre-harvest, harvest and post-harvest management practices capable of reducing losses of both edible and carving pumpkins during storage.

Specific project objectives are:

1. To collate and disseminate information on management of the pumpkin crop in the US, and associated research relevant to the UK industry.
2. To determine and rank the main forms of post-harvest loss (tissue breakdown, latent infection, post-harvest infection, harvest maturity) currently affecting pumpkins in the UK.

3. To determine and rank the key factors affecting the storage potential of pumpkins in the UK (harvest maturity, mineral nutrition, harvesting/post-harvest practices, and storage environment/practices.)

4. To determine the varietal characteristics that affect storage potential (including size, skin strength, pericarp thickness, dry matter content)

5. To identify and test pre-harvest management practices to improve storage potential.

6. To identify and test harvest/post-harvest management practices to improve storability, including the identification of maturity indicators to predict storage potential at harvest.

In the first year of the project information was collated on growing and storage practices in the US, where the pumpkin crop is particularly important. This was followed up by a visit to several US states in October 2015. One key observation was that US growers conduct a concentrated programme of spraying against powdery mildew as they believe that damage to the stalk (or handle) provides an entry point for rotting pathogens into the fruit and therefore increases postharvest losses. During 2015 a field trial was conducted in Cambridgeshire to determine the advantages of powdery mildew control for Mars, Harvest Moon and Racer. Although an increase in fruit number was observed for Mars, and an increase in fruit size for all three varieties, there was no indication that the treatment reduces postharvest rots.

In both Cambridgeshire and Hampshire, the main cause of storage losses observed was *Phoma* (Figure A). In the final year of this project a spray programme against both *Phoma* and Powdery Mildew will assessed for efficacy and economic value.

Figure A. *Phoma* storage rot observed for pumpkins harvested in Cambridgeshire in 2015 and stored long-term to identify the main storage rots.

Varietal susceptibility to storage rots varies by growing location. A higher percentage of rots was observed for pumpkins from Hampshire compared to Cambridgeshire for Harvest Moon and Mars, while the difference was not so obvious for Racer. A possible link with calcium nutrition was observed which should be investigated further.

A preliminary survey of pumpkin characteristics of a range of varieties over two seasons suggests that there are consistent differences among varieties in fruit firmness (whole, skin and flesh). As pumpkin growers move into the culinary market and try out a wider range of varieties, it will become more useful to understand the relationship between these characteristics and keeping qualities. Simple storage trials will be conducted in 2016 to test these relationships.

Financial Benefits

Growers have reported postharvest losses of 7-35% in the field and 5-35% in stores. With the market for decorative pumpkins in the UK estimated to be at least £15M/year, this equates to losses of at least £1.5M annually and possibly 5 times greater than that. By reducing storage losses spray programme could help growers save up to 50% of these losses.

Action Points

Growers should consider spray programmes against *Phoma* in order to reduce storage losses.

SCIENCE SECTION

Introduction

The market for carving pumpkins, currently estimated at £14-15M per year is growing at a rate of 20% annually, and the market for culinary pumpkins at a similar rate albeit from a lower base. The levels of loss during storage are unclear, but are estimated to be 15-20% equating to an annual loss of £2-3M for decorative pumpkins alone. The overall aim of this project is to improve the uniformity and quality of pumpkins and reduce losses, thereby providing a significant increase in profitability for the UK pumpkin industry.

Carving pumpkins need to be stored and cured for approximately 6 weeks from harvest, usually in mid-September, until the end of October. It would be commercially advantageous to store culinary pumpkins until Thanksgiving (third week in November), equivalent to 9-10 weeks or longer if possible.

In the UK, storage is currently in uncovered windrows in the field, windrows within greenhouses, or in bins within stores (usually without refrigeration). Usually no specific temperature or humidity control is used, but in some cases there is forced airflow which will reduce the build-up of condensation. No ventilation within windrows is used.

Although losses are high there is little reliable information either on the main forms of loss (physiological, latent infection, post-harvest infection) or on the key factors (mineral nutrition, harvesting/post-harvest practices, storage environment/practices) affecting losses.

Growing region and variety

It has been observed that losses can vary by region, with lower storage losses reported for the variety Racer grown on the South coast compared to those under cultivation in East Anglia and it has been suggested that warmer temperature improves curing (skin hardening and healing) and / or that it prevents night-time condensation (dews that can increase the risk of rots). Likewise it is known that storage potential varies by variety; Mars is a variety with higher flesh content and with longer storage potential than similar sized pumpkins with thinner flesh (pericarp). However, there has been no detailed study relating phenotypical characteristics with storage potential.

Pre-harvest disease

Powdery and Downy mildew can lower yield and cause rots/plant loss in the field, respectively. Varietal resistance to Downey mildew is being bred for and is associated with fruit that retain dark green stems. Work has been done in the US on the impact of Downy

mildew on crop storage and the recommendations are to run a spray program up until the point of harvest.

US storage strategies

In the US more importance is given to storage conditions than in the UK, presumably indicating a greater value of the US crop. The UK pumpkin industry can potentially benefit greatly by exploiting US knowledge. For example in some states it is recommended that pumpkins are stored on shelves with no contact between neighbouring fruits. Removing soil from the outside of the pumpkin is considered good practice and other sanitation measures including washing fruits in drenching tanks prior to storage will reduce infection potential if the inoculum in the water flume can be controlled. Chlorine drenching can be an effective only when soil contamination is removed prior to drenching.

Ethylene

US research indicates that ethylene should be avoided during storage. Exposure to ethylene will result in degreening of squash with green rinds. Ethylene will also cause abscission of the stem, especially in less mature fruit.

Chilling injury

Pumpkins are chilling sensitive, thus storage for several months at 10°C and below may cause chilling injury. The key issue with chilling injured fruit is their textural quality loss due to alterations in membrane structure, which makes the produce more susceptible to rots and decay. On the other hand, for carving pumpkins short exposure to temperatures lower than 10°C is unlikely to cause damage that is of economic importance. Chilling injury may become a significant factor for the eating quality of culinary pumpkins due to the potentially longer storage periods. The challenge to extend the season for culinary pumpkins beyond November will require more sophisticated storage technology such as ethylene removal or use of SmartFresh (1-MCP) and better control over post-harvest diseases through the use of sanitising agents (ozone, hydrogen peroxide misting).

Curing/skin set

Curing or skin set can have a significant impact on improving the storage potential of fruit. In the US growers are advised to harvest at sufficient maturity, for example after senescence of the leaves, when the pumpkin skin has set (thickened and hardened). It has been noted that if disease kills the vines prematurely, there is a risk that the fruit will be harvested immature. US storage practices are designed to allow curing, thereby further strengthening the skin and healing harvest wounds, and so reducing the risk of pathogen invasion. It is therefore common practice by some growers to cure pumpkins for 10 to 20 days at 20 -

25°C with good ventilation (e.g. four air exchanges per day). Storage humidity is set 65-85% to reduce weight loss but prevent moisture and rotting.

Overall project Aim

To identify pre-harvest, harvest and post-harvest management practices capable of reducing losses of both edible and carving pumpkins during storage.

Specific project objectives are:

1. To collate and disseminate information on management of the pumpkin crop in the US, and associated research relevant to the UK industry.
2. To determine and rank the main forms of post-harvest loss (tissue breakdown, latent infection, post-harvest infection, harvest maturity) currently affecting pumpkins in the UK.

3. To determine and rank the key factors affecting the storage potential of pumpkins in the UK (harvest maturity, mineral nutrition, harvesting/post-harvest practices, and storage environment/practices.)

4. To determine the varietal characteristics that affect storage potential (including size, skin toughness, pericarp thickness, dry matter content)

5. To identify and test pre-harvest management practices to improve storage potential.

6. To identify and test harvest/post-harvest management practices to improve storability, including the identification of maturity indicators to predict storage potential at harvest.

The first year of this project, 2014, was a very difficult year for pumpkin growers. The warm summer resulted in early fruit maturation, and forced the growers to keep the crop for longer than usual before marketing. As a result the level of losses in the field and in stores was high. The losses quoted in questionnaires circulated to pumpkin growers as part of the project activities were 7-35% in the field and 5-35% in stores.

In a survey of information on pumpkins from US sources, including direct interaction with growers identified the fact that US growers perceive that the presence of mildew in the field can increase rots of the fruit, by causing damage to the stem due to infection of cut stems. As a result of this it was decided that there would be value during 2015 in conducting a trial to determine the potential to reduce losses through spraying against mildew.

An initial trial was carried out to characterise the quality of fruit from a range of pumpkin varieties, with the longer term aim to identify the impact of varietal characteristics on susceptibility to rots and storability. In the first season a large range in dry matter content was identified. It will be very interesting to determine what impact this has on storability. The general perception is that low dry matter for crops is associated with poor storability.

However, there have been observations for root crops such as sweetpotato and potato that within a species the opposite is true, so careful observations will be necessary.

The main activities carried out during year 2 to further the objectives were:

1. Review of information from the literature and from the US

2. Trials to determine the effect of variety, growing location and Mildew control on keeping quality of pumpkins with the following objectives:

   To test the hypothesis that mildew infection of the stalk increases rot incidence, and whether this in turn improves storability

   To test the effect of harvest date on storability

   To relate pumpkin characteristics to storability

3. Characterisation of a wider range of pumpkin varieties. This will enable us to select varieties of particular interest for further study in the final year of the project.

Materials and methods

Review of information from the literature and from the US

Peter Waldock visited the US in September 2015, in order to obtain information from growers and seed houses in California, New York, Ohio and Pennsylvania.

Determining the effect of variety, growing location and mildew control on keeping quality of pumpkins

A trial was planted in Lincolnshire with two half acre plots of each of 3 pumpkin varieties; Racer, Mars and Harvest Moon. For each variety one plot was managed with and one without a mildew control programme (see Appendix 3). The trial field plan is shown in Figure 1.

Crop walks were carried out through the season to assess incidence of pathogens and pests, and plant growth stage (using the scoring system set out in Table 1).

Table 1. Definition of plant growth stage used during crop walks

Stage	Plant Development Stage	Growth stage	Description
0	Germination/sprouting/bud development		
1	Leaf development (main shoot)	10 11 15 19	Cotyledons completely unfolded First true leaf expanding First 5 leaves expanding First 9 leaves expanding
2	Formation of side shoots/tillering	21 22 23… …29	First side shoot visible (>5cm) 2nd side shoot visible (>5cm) 3rd side shoot visible (>5cm)… …9th side shoot visible (5cm)
5	Inflorescence emergence (main shoot)		
6	Flowering (main shoot)	60 61 62 63… …65 67 69	First male flowers open First male flowers fall Female flowers open About 30% flowers open… …About 50% flowers open Flowers fading, majority of petals fallen End of flowering, all petals fallen
7	Development of fruit	72 75 76… …79	Ovary growing Fruit about half final size Fruit about 60% final size… …Fruit about 90% final size
8	Maturity of fruit and seed	81 85 86 87 88 89	Most fruits still green 50% fruits final colour Most fruits final colour Some stems dying off Skins hardening Harvest
9	Senescence		

In order to assess the effect of maturity on keeping quality, a preliminary harvest was conducted on 17th September 2015, approximately 2 weeks before the commercial cutting date, in which 30 pumpkins, selected to be less mature than average, were harvested for each treatment, and placed in wooden “onion” storage bins (approximately 1m x1m x0.8m).

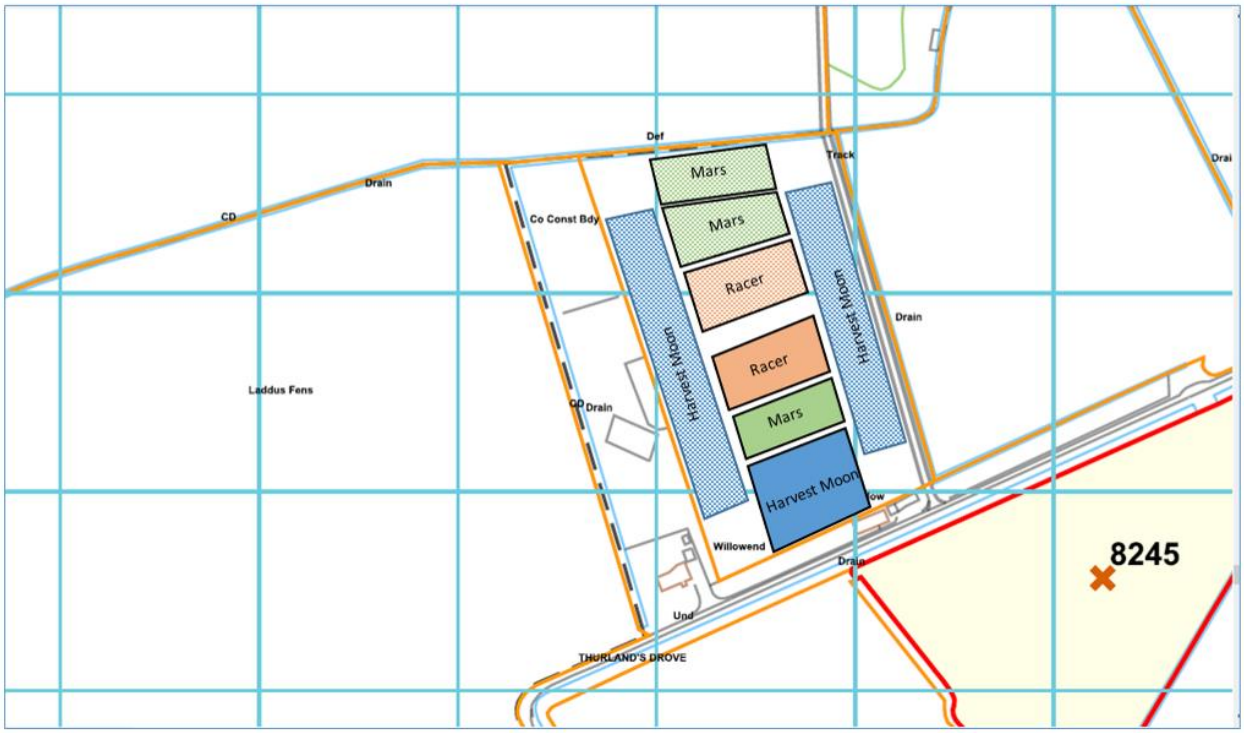
At this point 6 pumpkins were selected from each treatment and were transported to NRI for quality assessment (see below) which was carried out on 21- 23 September.

The main harvest took place on Wednesday 30th September 2015. Three 10m x 10m blocks were selected within each plot. All pumpkins within each block were harvested and the number of pumpkins recorded, categorised by size. The number of rotten pumpkins, with an identification of rot wherever possible, was recorded and representative samples of rotting pumpkins were taken to EMR for subsequent rot identification.

The saleable pumpkins from each block were stored in a wooden “onion” storage bin. At this point these bins and those set up in the early harvest were moved from the field and placed under cover in a glass house. 6 pumpkins were selected from each treatment were transported to NRI for quality assessment (see below)

In order to obtain information on the effects of growing location on pumpkin quality, additional bins of pumpkins (Harvest Moon, Mars and Racer) grown in Hampshire near the South coast were transported to EMR at the end of October and stored under cover, and other bins of pumpkins (Harvest Moon only) grown in Kent near to Leeds were also stored under cover on farm specifically for this project.

All the stored bins were assessed in the first week of December for external appearance for saleability and for incidence and identity of rots. Further pumpkin samples were transported to NRI for quality assessment.



Solid colours to be sprayed

Hatched colours untreated

Figure 1. Field plan for Lincolnshire trial

Pumpkin quality assessment

Skin colour was measured using a Minolta colour meter (*L*a*b** colour space) at 4 points around the fruit equator. This provided a measure of loss of green background (*a scale) and the increase in yellowing (*b scale).

The L* a*b*, colour space and Minolta colour meter used to measure machine colour values.

Whole fruit firmness was measured using a TA.XT plus Texture Analyser (Stable Micro Systems, UK) equipped with a convex-tip probe; 8-mm diameter. The probe recorded resistance whilst travelling 8.0 mm at a speed of 0.83 mm s^{-1} and the maximum force (N) recorded.

Samples were collected from a pumpkin cut into two halves longitudinally. The diameter of the pumpkin and thickness of flesh (pericarp) were both measured. Skin strength was measured on four cut sections of the equatorial strip using a TA.XT plus Texture Analyser (Stable Micro Systems, UK) equipped with a 2-mm diameter probe (puncture test) and a 50 kg load cell. The probe was driven 5.0 mm at a speed of 0.83 mm s^{-1} and the maximum force (N) recorded. Flesh firmness was measured on four sections from the flesh side using an 8 mm probe using the same parameters

Samples from the opposite eighths of the pumpkin (flesh with skin) were frozen and stored at -20 °C for subsequent mineral analysis. Samples of flesh were frozen in liquid nitrogen and stored at -80 °C for subsequent sugar analysis. Other samples were taken, weighed and dried in an oven to determine dry matter content.

*Mineral content (*N, Ca, K, B, Fe, Mg, Mn, P, Zn, and Cu.) analyses were conducted by the Fruit Advisory Services Team (FAST).

a  b  c 

Figure 2. a) TA.XT plus Texture Analyser used to carry out texture measurements. Cut sections used for b) skin strength and c) flesh firmness assessment.

Collection and analysis of rot samples

Samples of rotting pumpkins were taken to EMR for identification of causative agents. Samples were taken from the leading edge of the affected tissue and plated onto potato dextrose agar (PDA). Growing cultures were then identified under the microscope by

morphology. In specific cases molecular techniques (sequencing phylogenetically informative regions) were used.

Varietal Characterisation

Tozer seeds grew a varietal evaluation trial with 34 varieties and approximately 12 plants (to produce 12 fruits) of each at Cobham. After curing in the field 6 fruits per variety were selected for analysis at NRI. The varieties were selected with advice from Tozer. Six of the varieties overlapped with the varieties assessed in 2014.

Results

Review of information from the literature and from the US

The full report of a visit to the US carried out by Peter Waldock is included as Appendix 1. The key findings relevant to the objectives of this project are:

- The US market for pumpkins is much larger per capita than in the UK. Decorative pumpkins are distinct from those used to make pumpkin pie. The latter are usually sold in processed form. Decorative pumpkins are cleaned (sometimes waxed) and are sold over a much longer period than in the UK, as American's will buy sequentially to display outside their houses. Consequentially American growers do not need to store pumpkins.
- Americans tend to prefer larger pumpkins than in the UK
- American growers usually have an intensive spray programme against powdery mildew (every 7-10 days) as the visual quality of the stalk (handle) is very important and they perceive that rots enter the fruit through damaged stalks.
- American growers have a variable fertilisation programme
- Breeding programmes include focus on resistance to powdery mildew, and good stalk attachment to the fruit.
- Varieties are defined in terms of their rate of maturation (unlike in the UK).

Determining the effect of variety, growing location and Mildew control on keeping quality of pumpkins

Observations during growth

The observations made during crop walks are described in Appendix 2 but briefly, growth stage progressed between varieties fairly similarly through the season with Mars slightly ahead of the other varieties. Sprayed plots were slightly delayed in development at the first crop walk but subsequent crop walks were at the same growth stage as the unsprayed plots. The initial delay may have more to do with the field position rather than the treatment (these were unreplicated blocks). Powdery mildew was first observed on the 31/07/15 on unsprayed plots only. Powdery mildew was not observed on sprayed plots until 11/08/15. Disease pressure increased in unsprayed plots and was recorded as 'heavy' by the end of the season whilst only slight powdery mildew pressure was observed on the sprayed plots by the end of the season. Figure 5 shows the difference in disease control between sprayed and unsprayed crop.

Harvest observations

A subset of fruit was harvested on the 17th September approximately 2 weeks before commercial harvest time, and at a maturity stage considered young for commercial harvest (Figure 3). The commercial harvest was conducted on the 30th September (Figure 4).

Figure 3. Pumpkins harvested 2 weeks before commercial harvest and stored in a wooden "onion" storage bin.

Figure 4. Pumpkins harvested on 30 September (commercial harvest time) from 10m x 10m plots, and set out for assessment of size and rots.

The yield (in terms of number of pumpkins) was significantly increased for Mars variety sprayed against powdery mildew, but was not significantly affected in two other varieties, i.e. Harvest Moon and Racer (Figure 5). Spraying also increased the size of the pumpkins for all three varieties (Figure 7 a - c)

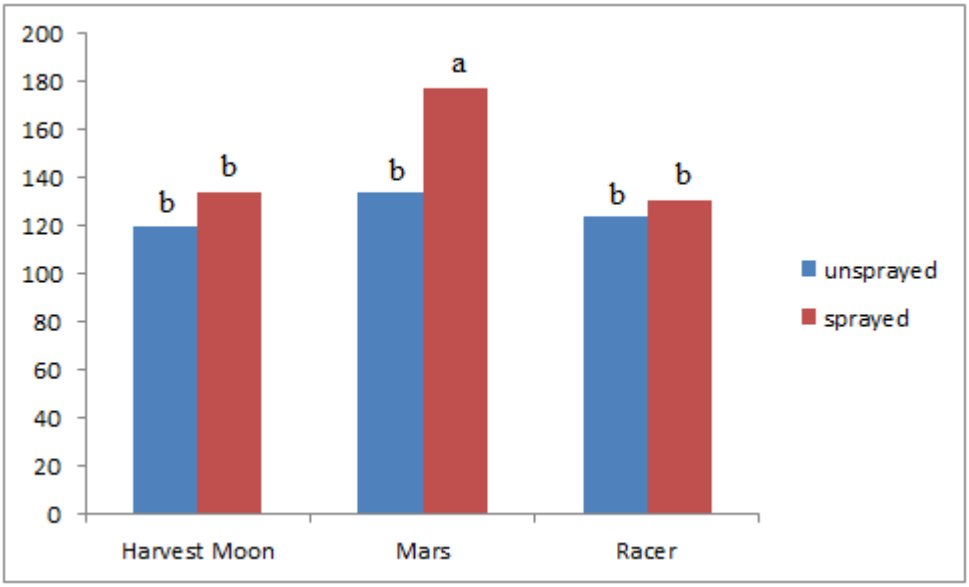


Figure 5. Yield of pumpkins (number) per 10m x 10m plot for three pumpkin varieties grown with and without spraying against powdery mildew. Different letters indicate significant difference (P<0.05) between the samples.

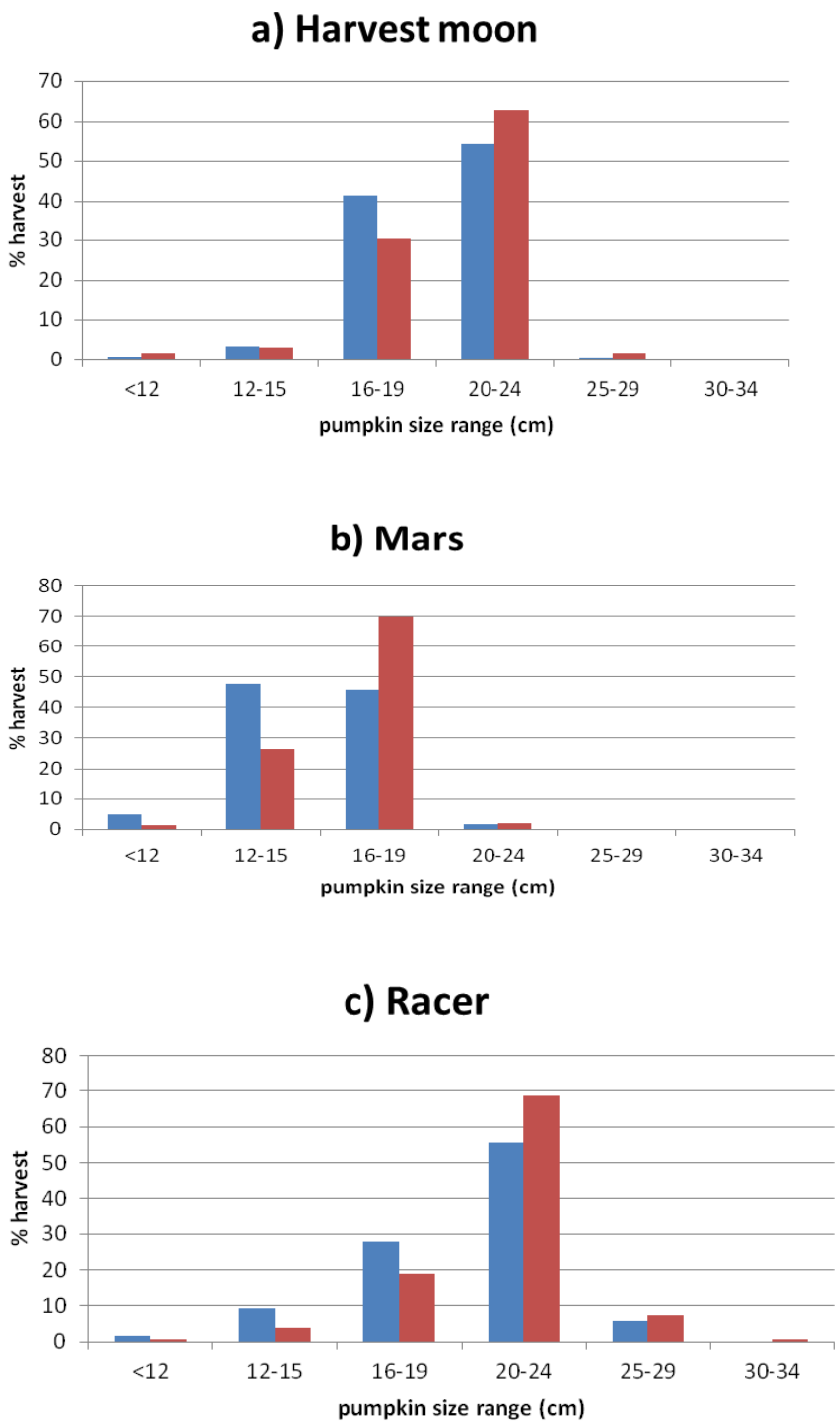


Figure 6 Harvested pumpkins categorised by size for each variety with (red) and without (blue) spraying against mildew. No statistical analysis has been carried out.

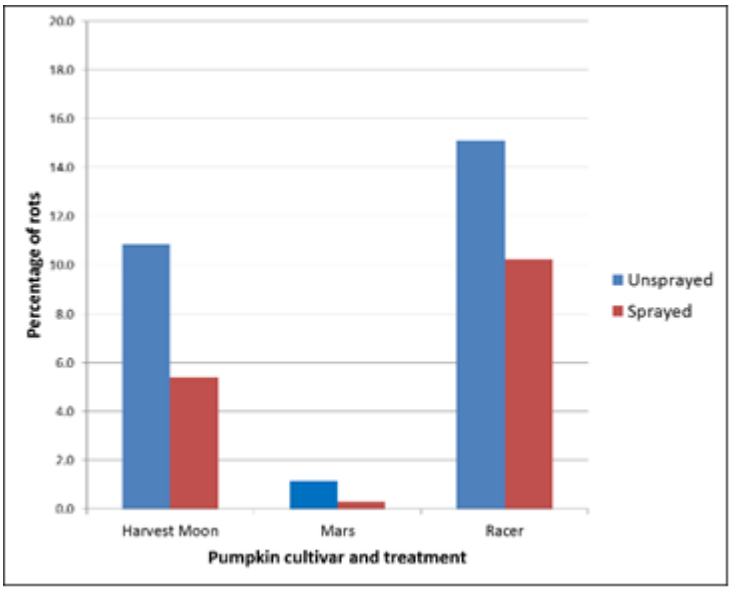


Figure 7. Percentage pumpkins with rots for each variety and treatment at harvest.

Table 2. Categorisation of rots at harvest in terms of position on pumpkin fruit.

		Total rots at harvest (%)	Position of rot as a proportion of total yield		
			Side	Stalk	Flower-end
Harvest Moon	Unsprayed	10.8	9.7	0.9	0.3
	Sprayed	5.4	5.2	0.2	0.0
Mars	Unsprayed	1.1	1.1	0.0	0.0
	Sprayed	0.3	0.0	0.3	0.0
Racer	Unsprayed	15.1	10.6	3.7	0.8
	Sprayed	10.2	6.7	3.6	0.0

The overall loss due to rots was greatest in Racer and least for Mars. There was a trend for a reduction in rots for sprayed plots however due to the variability of the yield and rots by plot there was no statistically significant difference between varieties or between treatments. The majority of rots observed at harvest were positioned on the cheek (side) of the pumpkin fruit. Flower end rots were low and were not observed at all in sprayed plots.

Assessment of rots and quality after storage

Figure 8. Storage of pumpkins in wooden “onion” bins under cover.

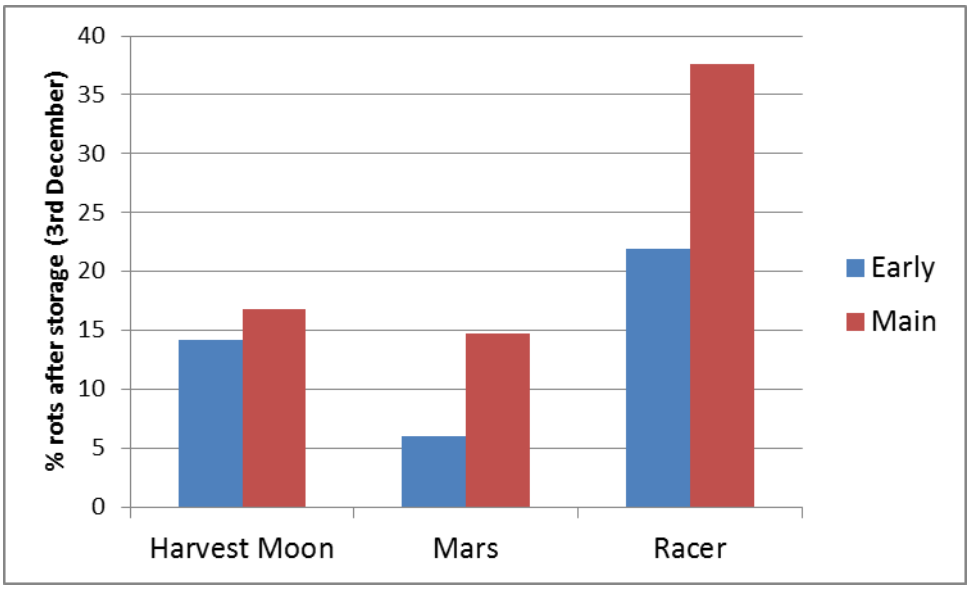


Figure 9. % rots after storage for three varieties and 2 harvest dates. 2 way ANOVA indicated significant varietal and harvest date effects. LSD = 12.3

More rots were found in the bins following storage of the main harvest (30th Sept) relative to the early harvest (17th September) (Figure 9). However, this might be a consequence of the smaller number of pumpkins in the early harvested bins, so that this observation needs to be repeated, to find out if it is of commercial value.

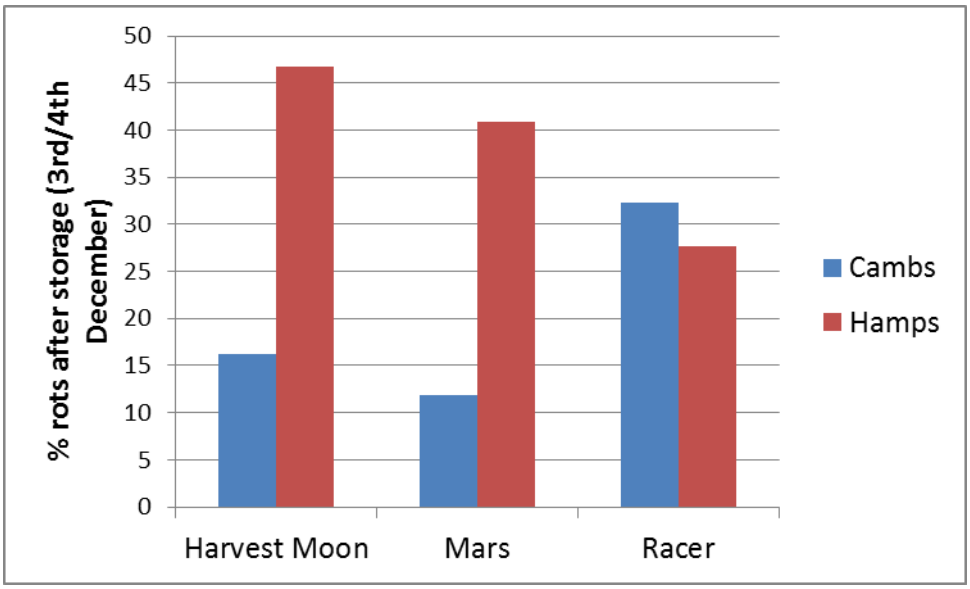


Figure 10. % rots after storage (on 3rd 4th December) for three varieties and 2 growing locations. No statistical analysis was carried out as only a single bin was assessed for each variety from Hampshire.

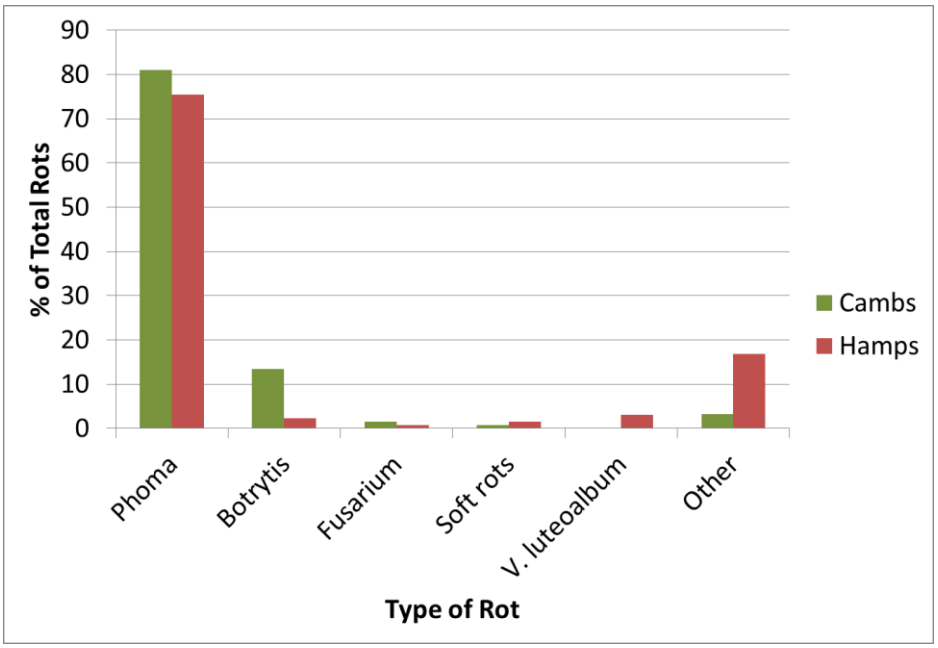


Figure11. Incidence of rot species observed across three varieties of pumpkin. Comparison between Cambridgeshire and Hampshire. No statistics carried out due to lack of replication.

Figure 10 shows the % rots observed after storage for pumpkins from two growing locations Cambridgeshire and Hampshire. A higher percentage of rots was observed for pumpkins from Hampshire compared to Cambridgeshire for Harvest Moon and Mars, while the difference was not so obvious for Racer. Although this result should be treated with caution as the storage conditions were not exactly the same, this does fit with the comments previously made by growers that different varieties suit different growing sites. No difference in incidence of rots by rot species was observed between the two locations (Figure 12) with *Phoma* being the main rot in both locations despite having markedly different crop rotations in each region (see Appendix 3).

There was no evidence for a benefit of mildew control on rot incidence (Figure 12), and no indication that spray treatment had any effect on the species of rots found (Figure 13).

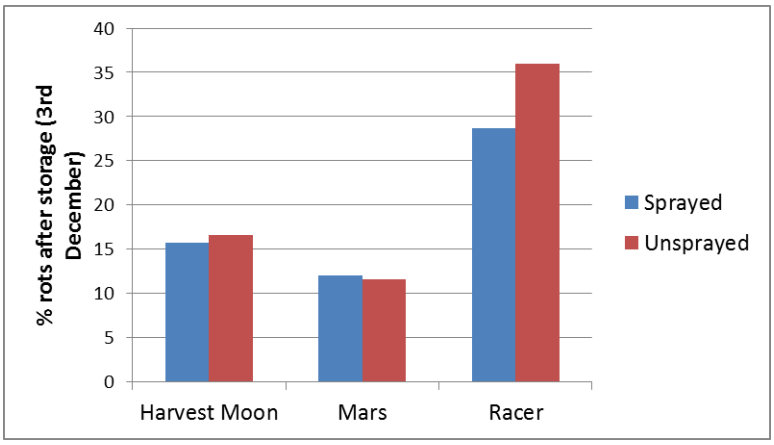


Figure 12. % rots after storage for three varieties with and without powdery mildew control. ANOVA indicated significant varietal effects but no significant treatment effects.

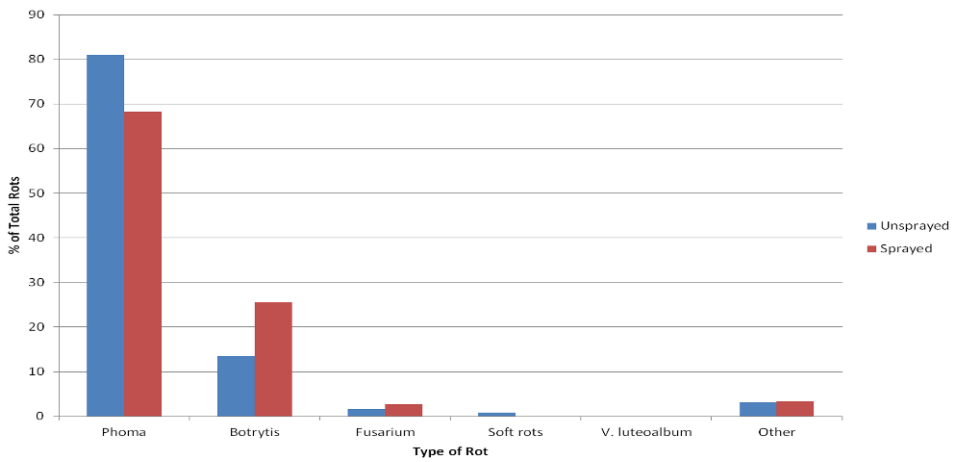


Figure 13. Incidence of rot species across three pumpkin varieties in Cambridgeshire trial, comparison between sprayed and unsprayed plots. No statistical analysis was carried out.

Quality assessment of pumpkins and relationships with keeping quality

Table 3. Mineral composition of the flesh of 3 pumpkin varieties grown with an without a spray programme against powdery mildew

	mg/100g Fresh weight					**mg/Kg Fresh weight**					**%**
Variety /treatment	**N**	**Ca**	**K**	**Mg**	**P**	**Cu**	**Fe**	**Mn**	**Zn**	**B**	**DMC**
Harvest Moon											
Sprayed	110.2	25.6	247.1	10.3	12.8	0.61	5.69	0.36	0.71	1.81	7.64
Unsprayed	111.8	27.5	267.3	10.7	14.3	0.41	4.56	0.35	0.71	1.72	7.97
Mean	111.0	26.5	257.2	10.5	13.5	0.51	5.13	0.35	0.71	1.76	7.81
Mars											
Sprayed	155.1	19.2	287.7	13.0	15.4	0.80	4.70	0.29	1.22	2.04	9.29
Unsprayed	116.1	19.4	322.7	9.9	12.3	0.42	4.94	0.18	0.77	2.07	6.87
Mean	135.6	19.3	305.2	11.4	13.8	0.61	4.82	0.23	1.00	2.06	8.08
Racer											
Sprayed	85.7	22.3	188.7	8.1	11.7	0.69	4.33	0.19	0.58	1.32	4.64
Unsprayed	80.0	23.2	191.3	7.6	8.6	0.29	5.13	0.16	0.50	1.37	4.22
Mean	82.8	22.8	190.0	7.9	10.1	0.49	4.73	0.17	0.54	1.34	4.43
Sprayed	117.0	22.4	241.2	10.5	13.3	0.70	4.90	0.28	0.84	1.72	7.19
Unsprayed	102.6	23.4	260.4	9.4	11.7	0.38	4.88	0.23	0.66	1.72	6.35
Varietal effect	ns	P< 0.001	p< 0.001	p= 0.03	ns	ns	ns	p= 0.018	ns	p< 0.001	p< 0.001
Treatment effect	ns	ns	ns	ns	ns	P <0.001	ns	ns	ns	ns	ns
LSD (variety x treatment)		5.3	63.1	3.8		0.21		0.2		0.42	2.08

Table 4. Mineral composition of the flesh of three varieties of pumpkin from different locations.

Variety/ Location	mg/100g Fresh Weight					mg/Kg Fresh Weight					%
	N	**Ca**	**K**	**Mg**	**P**	**Cu**	**Fe**	**Mn**	**Zn**	**B**	**DMC**
Harvest Moon											
Cambs	111.8	27.5	267.3	10.7	14.3	0.41	4.56	0.35	0.71	1.72	7.97
Hamps	76.6	15.1	154.4	8.0	8.2	0.33	2.09	0.49	1.51	1.24	4.36
Mean	94.2	21.3	210.9	9.3	11.2	0.37	3.33	0.42	1.11	1.48	6.17
Mars											
Cambs	116.1	19.4	322.7	9.9	12.3	0.42	4.94	0.18	0.77	2.07	6.87
Hamps	98.1	13.0	210.1	9.5	12.9	0.46	1.94	0.40	2.07	1.70	5.79
Mean	111.6	17.8	294.5	9.8	12.4	0.43	4.19	0.24	1.10	1.98	6.60
Racer											
Cambs	80.0	23.2	191.3	7.6	8.6	0.29	5.13	0.16	0.50	1.37	4.22
Hamps	63.1	31.8	213.3	11.2	7.8	0.26	1.91	0.44	1.15	1.52	4.79
Mean	73.2	26.7	200.1	9.1	8.3	0.28	3.84	0.27	0.76	1.43	4.45
Cambs	102.6	23.4	260.4	9.4	11.7	0.38	4.88	0.23	0.66	1.72	6.35
Hamps	75.7	20.3	183.3	9.3	8.8	0.33	2.00	0.46	1.48	1.41	4.74
Varietal effect	p< 0.001	p< 0.001	p< 0.001	ns	ns	ns	ns	p< 0.001	ns	p= 0.05	p< 0.001
location effect	p< 0.001	p=0.05	p< 0.001	ns	ns	ns	p< 0.001	p< 0.001	p< 0.001	ns	p< 0.001
LSD (variety x location)	51.7	8.6	117.3				2.58	0.13	0.85	0.83	3.13

Table 5. Colour of skin and flesh for 3 pumpkin varieties grown with and without a spray programme against powdery mildew. Measurements were taken after early harvest, the main harvest and following 9 weeks of storage.

	Harvest Moon		**Mars**		**Racer**	
	Sprayed	**Unsprayed**	**Sprayed**	**Unsprayed**	**Sprayed**	**Unsprayed**
	L* skin					
Early harvest	59.5bc	57.1d	51.6bc	50.4c	53.0b	55.9ab
Main harvest	60.1b	57.7cd	51.1c	53.5a	57.4a	59.4a
After storage	64.4a	60.9b	53.1ab	54.2a	57.6a	59.2a
	a* skin					
Early harvest	25.7c	26.0bc	24.9a	20.9b	17.6c	19.9bc
Main harvest	28.3ab	28.5ab	24.7a	24.6a	23.5ab	24.6ab
After storage	29.4a	29.9a	27.2a	26.9a	27.8a	26.5a
	b* skin					
Early harvest	53.5b	48.3d	39.1ab	35.8b	40.3b	43.6ab
Main harvest	52.7bc	48.9cd	39.0ab	40.7a	47.1ab	49.8a
After storage	60.1a	53.3b	41.3a	41.8a	46.8ab	48.7a
	L* flesh					
Early harvest	72.3ab	74.0a	74.5a	75.0a	73.3a	72.1a
Main harvest	67.6c	66.9c	70.8b	74.3a	70.8a	70.7a
After storage	76.0a	69.0bc	69.0b	73.8a	72.8a	70.8a
	a* flesh					
Early harvest	2.8c	1.9c	3.4d	4.8d	-1.2c	0.0c
Main harvest	6.1b	5.4b	12.8b	8.6c	4.5b	3.4b
After storage	6.9b	11.3a	20.7a	14.1b	7.9a	9.9a
	b* flesh					
Early harvest	50.4cd	51.1bcd	73.7abc	72.8bcd	44.2b	46.2b
Main harvest	54.1bc	56.1ab	75.3ab	70.2d	47.2b	48.0b
After storage	47.9d	60.5a	76.3a	71.3cd	54.2a	56.4a

Table 6. Fruit characteristics for 3 pumpkin varieties grown with and without a spray programme against powdery mildew. Measurements were taken after early harvest, the main harvest and following 9 weeks of storage.

	Harvest Moon		**Mars**		**Racer**	
	Sprayed	**Unsprayed**	**Sprayed**	**Unsprayed**	**Sprayed**	**Unsprayed**
	Diameter (cm)					
Early harvest	22.6a	19b	17.5a	16.05b	19.35a	21.1a
Main harvest	21.3ab	20.1ab	17.2a	15.45b	20.95a	19.5a
After storage	19.9b	20.2ab	17.15a	16.35b	21.8a	20.95a
	Flesh thickness (cm)					
Early harvest	3.2a	2.7a	2.5a	2.4a	2.5a	2.5a
Main harvest	2.9a	2.8a	2.5a	2.3a	2.9a	2.5a
After storage	2.9a	3.0a	2.5a	2.2a	3.1a	2.7a
	Whole Fruit Firmness (N)					
Early harvest	46.1ab	50.92a	56.75ab	59.02a	35.75a	31.88a
Main harvest	46.62ab	52.97a	51.29ab	44.58bc	33.8a	26.64a
After storage	37.59b	47.3ab	34.5cd	29.31d	27.19a	32.04a
	Skin firmness (N)					
Early harvest	29.73a	33.72a	33.12a	30.51a	22.77a	22.87a
Main harvest	33.39a	32.76a	34.59a	27.34a	23.05a	20.58a
After storage	18.52b	30.86a	29.51a	30.67a	21.89a	22.97a
	Flesh firmness (N)					
Early harvest	103.5a	110.7a	131.92a	125.84ab	55.8a	61.62a
Main harvest	101.97a	105.98a	136.39a	115.2bc	60.69a	56.67a
After storage	63.64b	98.61a	129.8a	110.33c	58.1a	63.78a

Table 7. Fruit characteristics for three pumpkin varieties grown at different locations within the UK

	Harvest Moon			Mars		Racer	
Characteristic	**Hamps**	**Kent**	**Cambs**	**Hamps**	**Cambs**	**Hamps**	**Cambs**
L* skin	63.14a	63.99a	60.89b	55.08a	54.25a	56.59b	59.21a
a* skin	27.61ab	25.88b	29.90a	28.77a	26.95b	29.10a	26.46b
b* skin	60.90a	59.10a	53.29b	46.52a	41.84b	51.34a	48.74a
L* flesh	75.72a	76.81a	69.01b	75.75a	73.81b	75.28a	70.76b
a* flesh	4.97b	5.38b	11.33a	8.62b	14.05a	6.74b	9.92a
b* skin	41.04b	39.39b	60.51a	61.99b	71.27a	52.55b	56.40a
Diameter (cm)	22.46a	24.45a	21.72a	18.46a	18.52a	22.08a	23.73a
Height (cm)	18.68b	21.881	18.73b	14.90a	14.17a	17.05a	18.18a
Flesh thickness (cm)	3.0a	3.6a	3.0a	2.7a	2.2b	2.8a	2.7a
Whole fruit firmness (N)	29.07b	30.87b	47.3a	32.81a	29.31a	27.9a	32.04a
Skin firmness (N)	20.26b	23.89b	30.86a	32.79a	30.67a	25.57a	22.97a
Flesh firmness (N)	58.27c	71.43b	98.61a	105.41a	110.33a	61.77a	63.78a

Tables 3 – 7 summarise the characteristics of pumpkin fruits sampled from the trial on powdery mildew control conducted in Cambridgeshire and also of pumpkin fruits samples from Hampshire and from Kent. A comparison of characteristics with the storage characteristics indicates a possible relationship between calcium content and incidence of rots; high calcium appears to be related to low rots (Figure 14). No other relationship has been identified.

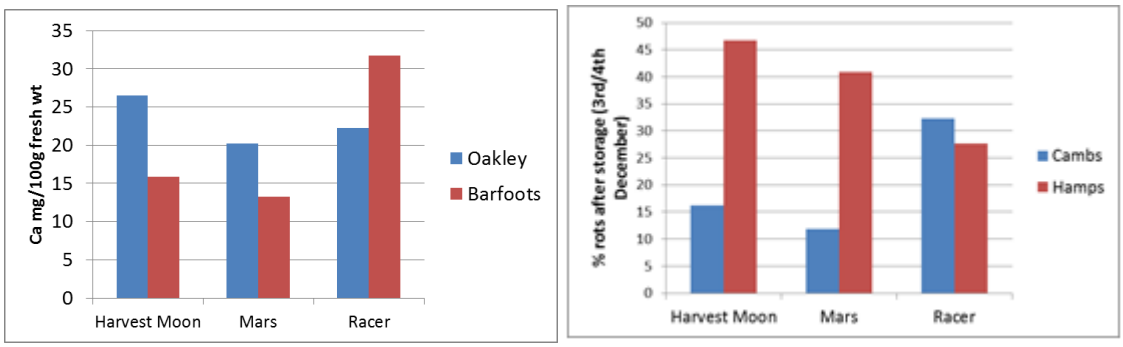


Figure 14. a) calcium content and b) percentage rots for three pumpkin varieties grown in two locations.

Another key observation is that fungicidal treatments lead to a significant increase in the copper content of pumpkin flesh

Review of pumpkin varieties

Twelve varieties of pumpkins, grown in a varietal testing trial by Tozer seeds were assessed for their fruit characteristics, with the objective of identifying contrasting varieties that can be studied in more detail in the final year of the project in order to relate fruit characteristics to keeping qualities. The varieties tested are shown in Figure 15.

Becky

Carrie

Cinnamon Girl

Hannibal

Mars

Paintball

Racer

Rocket

Small Sugar

Snowball

Sunlight

Touch of Autumn

Figure 15. Example fruit of twelve pumpkin varieties grown in a varietal testing trial and sampled for fruit quality assessment

The fruit characteristics; mineral content, colour of skin and flesh, size and firmness of fruit, skin and flesh are summarised in Tables 8-10.

Table 8. Mineral content of the flesh of twelve pumpkin varieties

	mg/100 g flesh					mg/Kg flesh					%
Variety	N	Ca	K	P	Mg	Cu	Fe	Mn	Zn	B	Dry Matter
Becky	99.57	15.10	366.81	28.55	6.38	0.22	3.23	0.17	0.46	2.29	7.12
Carrie	129.26	17.08	282.57	24.64	12.44	0.23	1.99	0.30	0.88	1.44	5.00
Cinnamon Girl	62.29	16.87	287.69	17.52	4.97	0.13	1.70	0.07	0.34	1.90	4.77
Hannibal	69.40	17.95	141.55	17.00	7.22	0.18	2.24	0.20	0.35	1.03	3.54
Mars	106.77	15.49	260.94	27.15	8.99	0.27	2.90	0.18	0.81	1.48	5.08
Paintball	129.95	29.28	373.75	33.63	12.64	0.16	3.17	0.27	0.42	1.95	6.66
Racer	74.57	18.90	192.91	18.94	7.88	0.15	1.95	0.28	0.49	1.25	4.01
Rocket	99.70	26.54	240.85	22.08	9.34	0.16	2.39	0.41	0.64	1.14	4.37
Small Sugar	79.28	16.05	364.23	23.68	7.38	0.20	2.58	0.17	0.32	2.04	7.03
Snowball	99.44	31.06	393.45	30.16	15.68	0.21	3.07	0.26	0.63	2.00	8.20
Sunlight	89.83	12.41	324.47	29.54	15.70	0.19	2.27	0.19	0.63	2.68	7.69
Touch of Autumn	181.82	16.05	443.70	54.49	17.70	0.50	3.60	0.31	1.45	2.47	11.25
Varietal effect (p)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.022	n.s.	<0.001	<0.001	<0.001
LSD	33.42	4.52	53.67	6.58	2.95	0.09	0.99		0.33	0.31	1.40

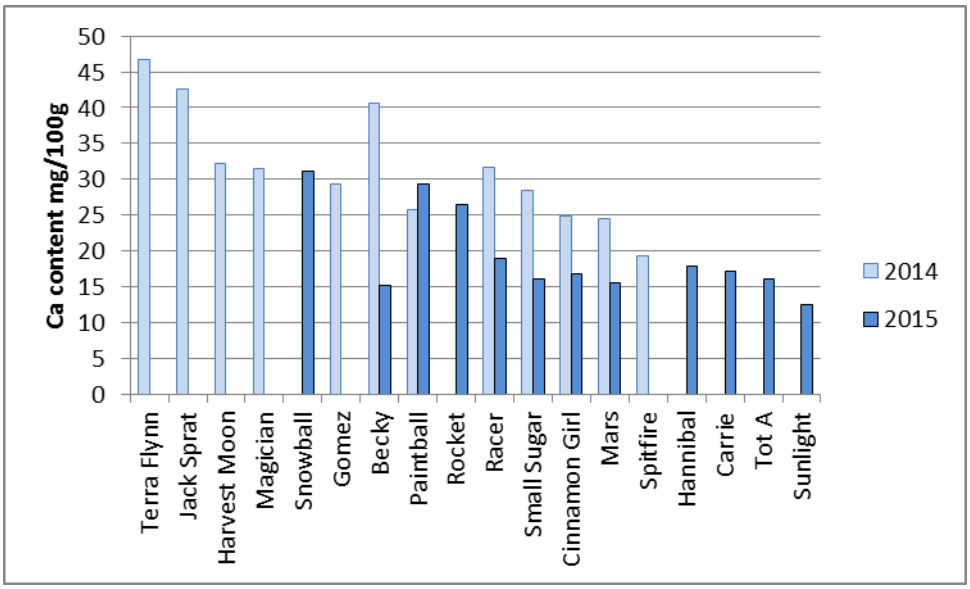
Table 9. Colour of skin and flesh of 12 pumpkin varieties measured using a Minolta colour meter. Each measurement is the mean of four measurements on 6 fruit.

name	L* skin	a* skin	b* skin	L* flesh	a* flesh	b* flesh
Becky	60.07bcd	28.97ab	55.22bcd	73.78cde	14.50a	76.17a
Carrie	56.25ef	29.06ab	50.76de	70.94efg	8.62b	54.13ef
Cinnamon Girl	62.21bc	26.95abc	59.59bc	79.01a	1.25f	52.65efg
Hannibal	59.33cde	28.49ab	54.75bcd	73.80cde	7.55bcd	51.17efg
Mars	50.95f	22.06c	40.30f	76.65abc	5.00de	68.50b
Paintball	55.65f	24.68bc	48.46e	72.78def	8.51bc	55.67de
Racer	58.14def	28.20ab	53.68cde	70.00fg	6.64bcde	48.93fg
Rocket	63.29b	28.46ab	59.79b	69.11g	6.51bcde	47.78g
Small sugar	56.28ef	23.11c	48.21e	74.66bcd	5.50cde	65.22bc
Snowball	88.78a	-0.67e	20.43g	78.29a	-2.06g	32.25h
Sunlight	78.94a	10.44d	76.45a	76.98ab	4.34ef	50.86efg
Touch of Autumn	58.66def	31.16a	52.62de	77.14ab	5.29de	60.61cd

Table 10. Fruit characteristics of twelve pumpkin varieties. Each value is the mean of measurements on 6 fruit.

name	Diameter (cm)	Height (cm)	flesh thickness (cm)	Whole fruit firmness (N)	Skin firmness (N)	Flesh hardness (N)
Becky	15.25de	11.42de	2.3cd	50.88ab	36.22a	122.02b
Carrie	26.98ab	19.42b	3.4b	41.5bcd	26.52cde	91.82c
Cinnamon Girl	15.37de	12.20de	1.7d	28.36e	26.01cde	85.05cd
Hannibal	29.12a	25.60a	4.5a	33.67de	25.59de	80.82cd
Mars	18.15cd	13.82cd	2.5c	38.36cde	24.27e	111.3b
Paintball	19.65c	15.03c	2.2cd	40.15bcde	28.19bcde	83.6cd
Racer	25.52b	19.08b	3.8ab	33.03de	24.83e	60.79e
Rocket	27.78ab	25.17a	4.1ab	38.67cde	24.34e	72.56de
Small sugar	16.53cde	13.30cde	2.2cd	46.39abc	30.18abcde	126.07b
Snowball	13.68e	11.18e	1.8cd	51.41ab	34.81ab	82.39cd
Sunlight	18.05cd	13.38cde	2.2cd	57.42a	32.18abcd	111.25b
Touch of Autumn	14.58e	12.37de	2.3cd	54.81a	33.2abc	143.03a

a)



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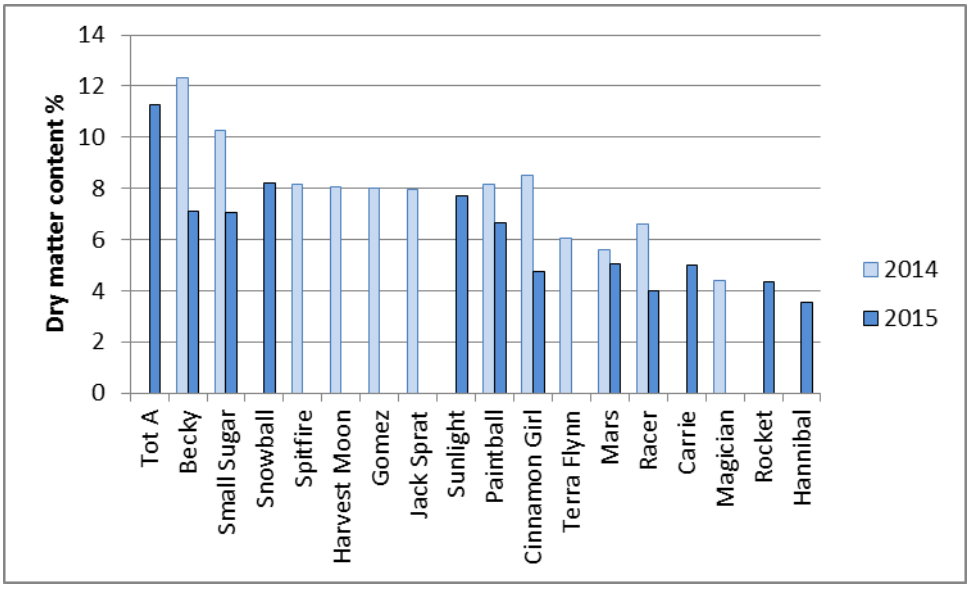

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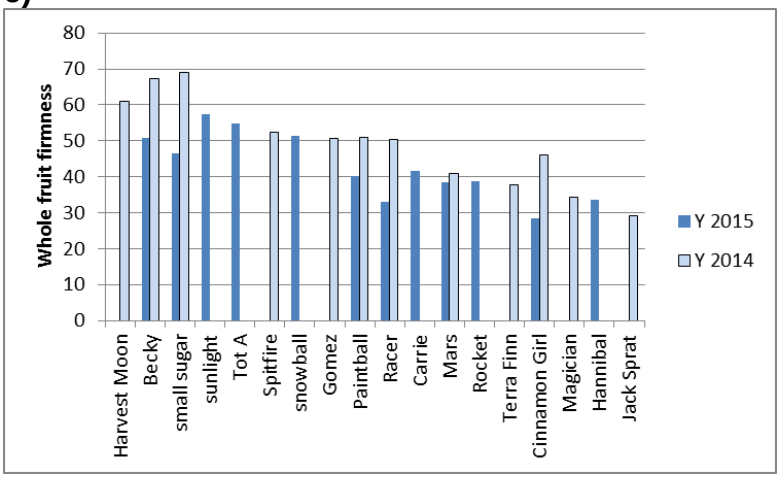

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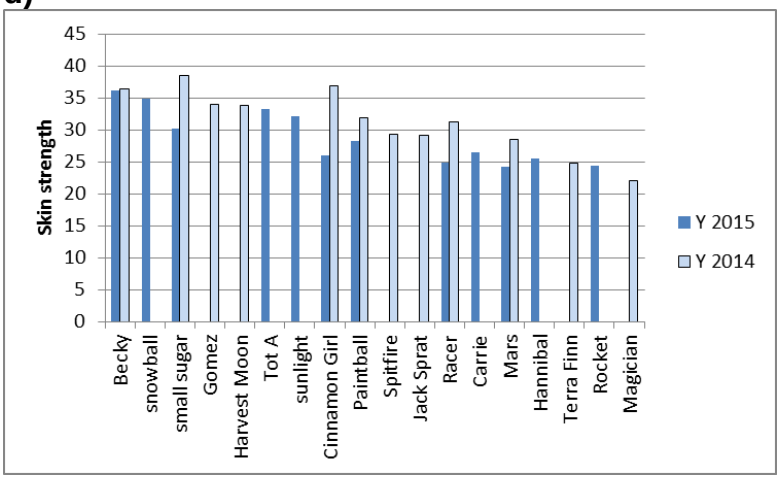

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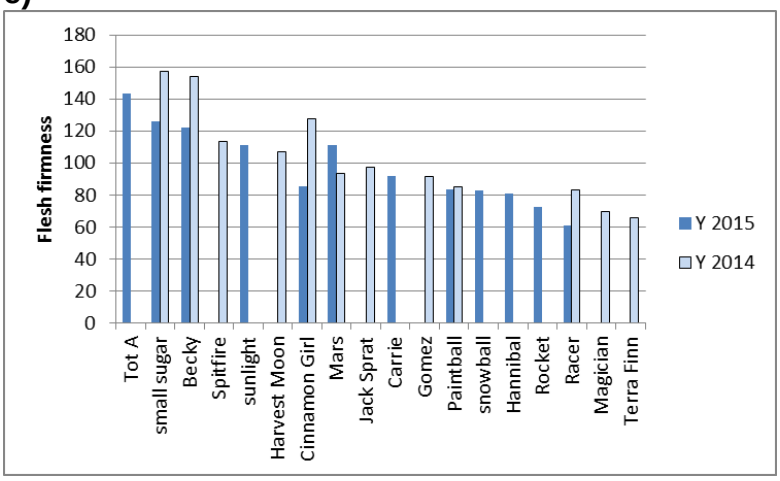

Figure 16. A comparison of data from a range of pumpkin varieties assessed over 2 seasons a) Ca Content (mg/100g) b) Dry matter content (%) c) whole fruit firmness (N) d) skin firmness (N) e) flesh firmness (N). Each data point is the mean of measurements carried out on 6 fruit.

Figure 16 compares key characteristics measured this year with those measured in the previous season. Due to the different availability of varieties each year only 6 varieties were common between the two seasons. Both Calcium content and dry matter content seemed variable between seasons, whereas firmness (whole fruit, skin and flesh) looked more consistent with varieties that were consistently firmer (e.g. Becky) and those that were consistently softer (e.g. Racer).

Discussion

The trial on the effects of spraying against powdery mildew was carried out to test the perception in the US that this reduces postharvest losses due to rotting. The trial was conducted on three varieties and there was an indication that the incidence of rots at harvest was lower for treated field plots. However the data was too variable for clear conclusions, and no difference could be seen after storage. In the US growers do not store pumpkins, due to the consumer habit of sequentially buying pumpkins through the season. This means the US grower perceptions are likely to relate to losses in the field and up to harvest and not at a later stage. Treatment did however increase yield (in terms of pumpkin number) significantly for Mars, and resulted in an increase in pumpkin size for all three varieties. A spray programme against powdery mildew could be advantageous for growers if planting density is chosen to give the appropriate pumpkin size range for the market. Further trials would be justified, and may provide clearer data on whether or not there is an advantage in terms of postharvest losses.

Several quality characteristics were measured for sprayed and unsprayed fruit but very few clear patterns emerged other than those discussed above. However there was a clear increase in copper content for flesh of sprayed fruit indicating that there is a route for copper absorption.

The observation that the incidence of rots is lower for pumpkins harvested less mature would also be worth investigating in later seasons.

UK growers often state that the behaviour of certain varieties is very dependent on location. This view is supported by the observation that a higher percentage of rots was observed for pumpkins from Hampshire compared to Cambridgeshire for Harvest Moon and Mars, while the difference was not so obvious for Racer. This observation provides an opportunity to relate pumpkin physical characteristics to keeping qualities. Among the characteristics considered, the only one that appeared to relate consistently to storability was calcium content. Calcium is very important for fruit quality and has been implicated in resistance against pathogens. Improvements in calcium nutrition might be one route to reducing losses.

Skin colour is an important quality characteristic for carving pumpkins. A bright orange is preferred. The a* value of the L*a*b* colour space describes redness; the higher the a* value the more red. On this basis there was no clear advantage of spraying against powdery mildew (Table 5). However, there was an indication that Mars and Racer produced in Hampshire might have a better colour than that produced in Cambridgeshire (Table 7). The effect of growing conditions on skin colour is outside the scope of this project, but could be economically valuable.

During both the first and second season of this project a range of varieties were assessed for their quality characteristics. Unfortunately only six varieties were common to both seasons. The objective is that the data obtained will be useful in identifying varieties that have good keeping qualities. However, to achieve this it will be important to carry out a storage assessment alongside the quality assessment.

Conclusions

- Control of powdery mildew increased the harvest yield in terms of number of fruit for Mars. The same trend was observed for Harvest Moon and Racer, but was not statistically significant. For all three varieties the treatment increased the size of fruit (although no statistical analysis was carried out).
- In the field, mildew control reduces flower end rots at harvest, which may suggest more flower end rots in unsprayed plots during the season lead to decrease in yield.
- There is no evidence that mildew control reduces storage rots.
- In this year's trials storage rots were lower for early harvested pumpkins compared to the main harvest, but this result may have been compounded by the lower number of pumpkins in the storage bins for the early harvest.
- Varietal susceptibility to storage rots varies by growing location. A higher percentage of rots was observed for pumpkins from Hampshire compared to Cambridgeshire for Harvest Moon and Mars, while there was no clear difference for Racer. A possible link with calcium nutrition should be investigated further.
- *Phoma* is the main cause of storage loss at both sites assessed..
- A preliminary survey of pumpkin characteristics of a range of varieties over two seasons suggests that there are consistent differences among varieties in fruit firmness (whole, skin and flesh).
- Treatments involving copper lead to an increase in copper concentration in the pumpkin flesh.

Priorities identified for next season

The following priorities have been identified for the final season of this project.

- Field trials to test fungicidal control against powdery mildew and phoma
- Storage trials for appropriate interventions for storage structures, especially considering effect of ventilation on losses
- Varietal trials to investigate the relationship between fruit characteristics and storability.

The following priorities have been identified but are outside the scope of this project.

- Trials to test the hypothesis that fruit picked less mature have better storability and exhibit a lower level of storage rots.
- Trials to determine the potential to improve storability through improved calcium nutrition.
- Trials to determine the impact of growing conditions on skin colour.

Knowledge and Technology Transfer

Marcin Glowacz attended the International Symposium on Cucurbits in Cartagena, Spain in June 2015 and gave a presentation entitled "Physicochemical characteristics of twelve pumpkin varieties grown in UK" This was funded by the University of Greenwich.

Peter Waldock gave a presentation on the project progress to the Outdoor Cucurbits Grower Group R&D meeting in January 2016.

Acknowledgements

We would like to acknowledge Oakley Farms, Barfoots, Dan Mackelden and Tozer Seeds for invaluable support through this year of the project. Oakley Farms carried out the field trial on Powdery Mildew control and the subsequent storage trial. Dan Mackleden and Barfoots provided us with pumpkins for the storage trial. Tozer Seeds allowed us to observed their variety trials and to take samples for analysis.

